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AVERAGE DAILY AIR MASS

By ROBT. E. KENNEDY

[U. S. Bureau of Reclamation, Denver, Colo., October 1940]

Studies involving the computation of solar heat available throughout the day require the use of the average daily air mass, or average length of the path in the atmosphere through which the sun's rays must pass as the sun travels across the sky. The air mass ranges from unity at the zenith to about 27 times the zenith value at sunrise or sunset.

Figure 1 provides a means of ascertaining the average air mass at any place on the earth for any day of the year. This figure is the north half of the chart; it is applicable to the Southern Hemisphere by changing signs. It is believed to be accurate within 2 percent for air masses up to 4.0; from there the accuracy shades off to about 5 percent in those parts of the polar region where the change with respect to latitude is rapid as the air mass value approaches 27.0. This limiting line marks accurately the edge of the polar night.

The computation of the chart involves the use of the well-known formula for parallactic angle

$$\text{Cos } Z=\sin \phi \sin \delta+\cos \phi \cos \delta \cos t \qquad (1)$$

in which Z=zenith angle of sun, ϕ=latitude, δ=declination and t=hour angle. The declination of the sun changes so slowly from day to day that it may be assumed constant for any one day without appreciable error. Then equation (1) reads Cos $Z=a+b \cos t$ in which a and b are constants. When the zenith angle is 60 degrees or less, an adequate approximation to the air mass is sec Z; values for 60° to 89° have been published in the *Smithsonian Meteorological Tables*, table 100, page 226, fifth edition, 1931. In the latter range, refraction enters in an increasing amount.

One method of computing the average daily value is to assume the air mass thickness to be equal to the secant of the zenith distance at all times. Then $\int \frac{dt}{a+b \cos t}$ provides a means of computing the area under the secant curve. Dividing the area by its base width, the total hour angle, t, from noon to sunset for the particular latitude and declination, gives an average secant height for the curve which is approximately the average daily air mass. This method is correct; but the assumption yields results too large by 12 percent at the Equator, and 16 percent at latitude 60°, for declination 23°27′.

The introduction of refraction, however, produces a curve which is not readily integrable; so resort was made to a graphical method of obtaining the area:

The zenith angle was computed for a number of hour angles, and the corresponding air mass taken from table 100 above referred to. Ten or fifteen points were usually sufficient to adequately define the pattern of the air mass curve, which was of course similar to the secant curve. The area was obtained by adding the ordinates, usually by single degrees except for the first 30° to 50° where the curve was comparatively flat and a 5° unit was used. Dividing the area by the base width gives the average air mass for that particular day and locality. To avoid duplicating this laborious process for every day of the year and every latitude, advantage was taken of the slow daily change of declination. Five or six days a year for 12 latitudes were found sufficient to define the pattern of the curves on figure 1.

These data, as assembled in table 1, were first plotted on two preliminary sets of large-scale curves. On one the air mass was plotted against declination, and on the other it was plotted against latitude. Points taken from these curves were required to fall in smooth lines on figure 1. Only occasional and small adjustments on the preliminary curves were necessary for this requirement, and the uniformity of their pattern was not impaired. This encouraged confidence in the accuracy of the computations.

TABLE 1.—*Average daily air mass*

Latitude	Declination										
	South					North					
	−23°27′	−20°	−15°	−10°	−5°	0	5°	10°	15°	20°	23°27′
90						26.96	10.39	5.60	3.82	2.90	2.50
85					26.96	15.28	10.90	6.34			
80				26.96	14.50	9.76	7.80	7.54	4.96		2.66
75			26.96		9.86	7.40	6.36	5.81	6.14		3.25
70		26.96	14.48			6.25	5.38		4.84		4.62
66°33′	26.96		10.25			5.45			4.39		4.99
63									4.10		4.19
60	12.29		7.17			4.61			3.89		3.86
55									3.57		3.48
50	6.67		5.04			3.83			3.35		3.30
45											
40	4.86		4.08			3.41			3.08		3.02
35											
30											
23°27′	3.59		3.26			2.93			2.80		2.82
20											
15						2.82			2.74		2.80
10											
5											
0	2.93		2.82			2.72			2.82		2.95

In application, this air mass factor is used in Beer's Law. Let I_o equal the solar intensity at the exterior of the atmosphere, and I the intensity at the bottom of the atmosphere, both taken normal to the sun's rays; then $\frac{I}{I_o}$

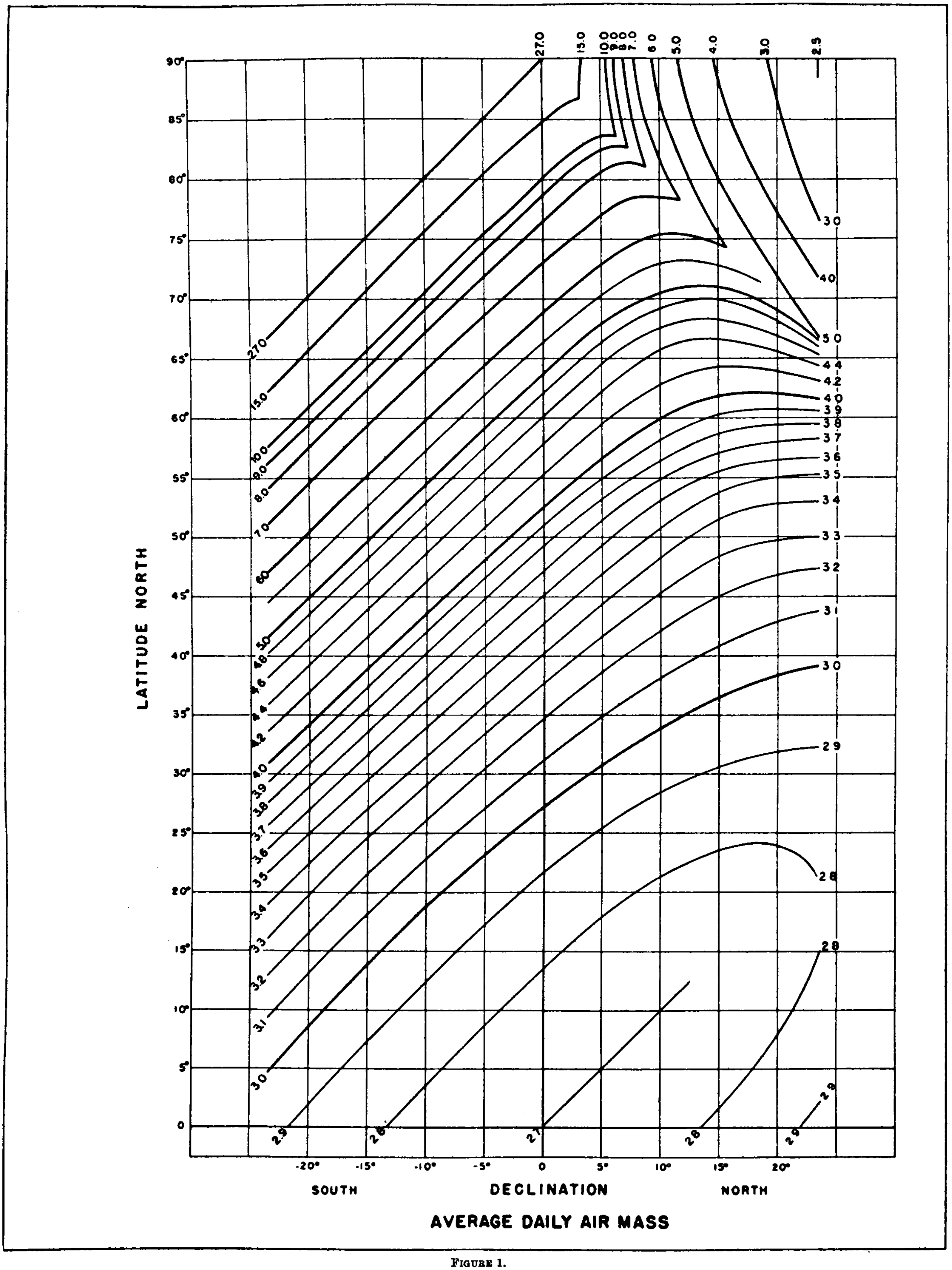
LATITUDE NORTH
DECLINATION
SOUTH
NORTH
AVERAGE DAILY AIR MASS

FIGURE 1.

is the ratio of atmospheric depletion, and Beer's Law in modified form is

$$\frac{I}{I_o}=a^m, \tag{2}$$

where a is the coefficient of atmosphere transmission, and m, the air mass, is the exponent.

The factor $\frac{I}{I_o}$ has been plotted against air mass, m, by Kimball for several stations in figure 1 of his paper, "Atmospheric transmission coefficients at various altitudes," page 2, MONTHLY WEATHER REVIEW, January 1935. The discussion is continued by Hand in the December 1937 issue; Hand's figure 15, page 427, gives graphically values of a in equation 2 for air masses from 1 to 5.

AEROLOGY IN THE HURRICANE WARNING SERVICE

By GORDON E. DUNN

[Weather Bureau, Jacksonville, Fla., February 1939.]*

The great improvement in the scope and accuracy of the advisories and warnings of tropical storms issued by the United States Weather Bureau has been recognized quite generally, especially by the public on the South Atlantic and Gulf coasts. However, business interests and the general public in this area, encouraged by the constantly increasing efficiency of the Bureau's hurricane warning service, demand still further refinements which, at present, are difficult and often impossible to meet. Most of the senior forecasters will remember when occasionally, because of insufficient land and especially marine observations, hurricanes became "lost" for several days at a time until finally an isolated ship report or a Mexican coastal station would locate the storm many hundreds of miles from the forecaster's projected position. Although the hurricane winds would not often exceed 75 miles in width, in the first two decades of this century hurricane warnings would fly occasionally along many hundred miles of coastline before the storm eventually reached the coast.

The present highly efficient [1] collection of ships' observations in the Gulf of Mexico, Carribbean Sea and South Atlantic [2] Ocean at 7 and 1 a. m. and p. m. E. S. T., and the system of direct calls to ships for special observations during storm conditions should be largely credited to the late E. B. Calvert, formerly Chief of the Forecast Division of the United States Weather Bureau. The ship reporting system now in effect was discussed by Calvert before the 1935 meeting of the American Geophysical Union (1). With the increase in the frequency of observations and the number of vessels included in the system, together with the Coast Guard and Bureau of Lighthouses, the Weather Bureau can accurately locate, most of the time, the position of the storm and its direction and rate of movement.

However, there are other more complex forecasting problems brought about by the notoriously erratic behavior of tropical storms. They may slow to almost a complete standstill for a day or so, may make several turns in their paths, and may even make a complete loop. Some of these erratic movements are apparently pure freaks, such as in the case of the November 1935 storm, but most of them occur at the time a storm leaves the deep easterly current on the southern periphery of the great Azores anticyclone and commences its northward journey through the changeable upper-air currents over and to the east of the southeastern United States. When these latter currents are light, the storm will move very slowly, and when they are changeable the movement of the disturbance likely will be erratic.

Mitchell (2) states, "All tropical storms in the Northern Hemisphere apparently seek to move northward at the first favorable opportunity * * *. Any tropical storm will recurve into a trough of relatively low pressure that may exist when the tropical storm arrives in the same region * * *. No storm will break through and recurve until it reaches a region where south or southwest winds prevail and relatively low pressure to the northward is shown on the weather map."

Mitchell (3) has also discussed the influences of anticyclones on the direction of movement of tropical cyclones, and Bowie (4) has given several examples. Mitchell's conclusions seem, in the main, to be substantiated by the greatly increased observational material of today. Subnormal pressure along and immediately off the Atlantic coast is usually indicative that the normal or at least frequent easterly current aloft in the Florida-Bahamas region has been replaced by a south to west current. However, pressure conditions in front of an advancing hurricane are often flat and indefinite, and often deceptive as regards conditions aloft, consequently a more true and dependable picture of upper air conditions in the entire hurricane region is necessary before any real forecasting of changes in rate and direction of movement of these storms can be attempted.

This article is intended to present the status of aerology in the hurricane warning service at the present time. Upper-air information is obtained from observed cloud types and directions, pilot-balloon ascensions, airplane and radiosonde observations.

Cloud observations are the one source of upper-air information which has shown a deterioration during the past 20 years. At the present time, exclusive of regular Weather Bureau stations within the United States, only two stations, San Juan, Puerto Rico, and Swan Island in the western Caribbean, include cloud data in their regular surface observations. This unfortunate situation has come about through economies which have forced the elimination of precipitation as well as cloud data and through the use of an abbreviated figure code which does not include precipitation, cloud data, or the 3-hourly barometric changes and characteristics. All forecasters engaged in hurricane warning work have considered clouds, especially the cirrus types, important and helpful. The Cuban Jesuit meteorologists, from Viñes to the present time, who have contributed considerably to our knowledge of these storms, have emphasized the importance of clouds in the theoretical and practical treatment of hurricanes. The Rev. Father Eulogio Vazquez, S. J., Belen College, has recently reached further interesting conclusions (as yet unpublished) regarding the relation of upper-air currents to the movement of tropical storms which deserve consideration and trial by other meteorologists. The inclusion of cloud data in all possible land surface reports

*The author, now located at the Weather Bureau office in Chicago, Ill., has revised this paper, with the assistance of Warren O. Johnson of the Jacksonville office, to November 1940.

[1] Since the beginning of the war, there necessarily has been considerable decrease in the number of ship reports, because foreign as well as United States ships had been participating.

[2] The term "South Atlantic" as used in this paper applies to the south portion of the North Atlantic Ocean, or, more specifically, that portion south of latitude 35° N.